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REPORT OF INVESTIGATIONS/1994

A Field Trial for Sealing Abandoned Mine Shafts and Adits With Lightweight Concrete

By E. H. Skinner and L. A. Beckett

UNITED STATES DEPARTMENT OF THE INTERIOR

BUREAU OF MINES

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Cover photographs: Site of No. 22 shaft before (top) and after (bottom) shaft sealing project.

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Bruce Babbitt, Secretary

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cwt	hundredweight	lb/ft^3	pound per cubic foot
°F	degree Fahrenheit	min	minute
ft	foot	mm	millimeter
ft^3	cubic foot	oz	ounce
gal	gallon	psi	pound per square inch
h	hour	qt	quart
in	inch	rpm	revolution per minute
kV	kilovolt	s	second
lb	pound	yd^3	cubic yard
lb/ft^2	pound per square foot	yr	year

A FIELD TRIAL FOR SEALING ABANDONED MINE SHAFTS AND ADITS WITH LIGHTWEIGHT CONCRETE

By E. H. Skinner[1] and L. A. Beckett[2]

ABSTRACT

An abandoned mine shaft near Omar, in Logan County, WV, was permanently sealed through a cooperative agreement between the West Virginia Department of Commerce, Labor, and Environmental Resources, Division of Environmental Protection, and the U.S. Bureau of Mines (USBM), Abandoned Mine Lands (AML) Program. An engineered shaft seal design was developed and demonstrated that featured lightweight concrete as a key material component at a wet density of about 45 lb/ft^3. A reinforced concrete cap designed for 5 psi live load was placed over the shaft seal. Applicable new concrete technologies relating to a 100-yr design life were utilized to assure future integrity of the shaft seal. Waterproofing methods were included in the shaft seal design to provide protection from ambient moisture and corrosive mine waters and to increase the long-term durability of the shaft seal. All construction methods used in the field trial are fully adaptable for the mine-reclamation contractor. The USBM research objectives were to develop a broad generic design that will be widely applicable to other adit-sealing and shaft-sealing problems throughout the mining industry.

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INTRODUCTION

The 1977 Surface Mining Control and Reclamation Act (PL 95-87) recognized reclamation on abandoned mine lands as a nationwide program. A portion of that act authorized funds for research and demonstration projects directed to mining and resource problems. Among the research provisions was an emphasis on new technology, engineering, and planning details. The act provided for reclamation of active mines, while mines abandoned before August 3, 1977, were placed in a special category for remedial work, the subject of this investigation.

U.S. Bureau of Mines (USBM) work described in this Report of Investigations (RI) was performed on a mine shaft abandoned before August 3, 1977, hence it came under the jurisdiction of the abandoned mine lands (AML) portion of the act. In 1987, the AML research program was transferred from the Office of Surface Mining (OSM) to the USBM, and Congress authorized funds to go directly to the USBM for AML research.

The primary considerations for this shaft-sealing program included (1) a life span of at least 100 yr, taking into account possible mining and flooding along Pine Creek, (2) the immediate and long-term surface stability of the shaft and the collar, (3) the durability of all concrete components, especially that of the lightweight concrete, and (4) overall project safety, not only to project personnel, but also to the public at large. All design decisions were approached from a conservative viewpoint, with the project goal being to assure maximum possible life and durability of the seal.

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BACKGROUND

Abandoned mine workings are a known hazard. They are often brought to the attention of the general public after a tragic accident has been reported in the local newspapers. Open shafts that have been abandoned are especially dangerous, not only to the unsuspecting public, but also to venturesome individuals not well versed in the hazards of abandoned mines. Although no exact number of nonmining-related accidents on unreclaimed mined lands is available, in 1992, The Coal Chronicle reported 89 fatalities since 1977 (*1*).[3] Also to be mentioned is the unfortunate loss of domestic livestock and wildlife that wander into abandoned mines.

The present shaft sealing project for abandoned mines was funded by the USBM in fiscal year 1990 through the proposal, "Rigid Foam Seals for Abandoned Mine Shafts and Adits." Although the original proposal envisioned investigation of a wider variety of materials, the AML directive restricted the work to foamed, or cellular, lightweight concrete. Subsequently, lightweight concrete became the featured material for this project.

In prior work not related to AML, the USBM devised inverted pyramid-shaped plugs for a demonstration of the closure of selected mine shafts in the Tri-State Lead-Zinc Belt near the town of Galena, KS (*2-3*). Many of these shafts lay within the Galena city limits and had been left open or the original timber lining had decayed. For the demonstration, truncated pyramid-shaped, reinforced concrete formworks were prefabricated at a local machine shop, transported to the mine sites, and erected with a crane over each mine shaft. Concrete was then placed in the formwork. Topsoil was used to backfill and cover the shaft. A permanent marker was embedded into the concrete.

This demonstration project was part of a broader study of the Tri-State Lead-Zinc Mining District in which 1,400 open mine shafts and nearly 500 mine-related subsidence features were identified and cataloged. These numbers may be similar to numbers found in other mining districts.

[3]Italic numbers in parentheses refer to items in the list of references preceding the appendixes at the end of this report.

Other recent AML work was reclamation by the State of Colorado's Inactive Mine Program (*4*). This program has involved the sealing of surface mine entries and small shafts with polyurethane foam at a density of about 2 lb/ft^3. For shafts, timber staging is manually placed about one shaft diameter or more below the shaft collar, depending on local ground conditions. Liquid polyurethane is then pumped into the shaft, where it expands and solidifies. Most of the efforts in shaft sealing have centered around Leadville and Central City, CO. This mine reclamation program has resulted in sealing nearly 200 abandoned mine shafts as of midsummer 1993.

The Pittsburgh, PA, office of OSM has also completed designs for abandoned mine seals. In 1983, as part of a project known as the Horner Subsidence Project in Shinnston, WV, gravel columns injected with concrete grout were placed and tested in an accessible portion of an abandoned mine (*5*). Results of that test revealed that contact with the mine roof was difficult to achieve with injected grout. Shortly after, support columns constructed of fabric and filled with lightweight concrete were tested at the Hagan Portal Subsidence Demonstration Project at Yorkville, Jefferson County, OH. There, eight 12-ft-high, woven nylon bags and two 6-ft-high, plastic fabric bags were successfully filled by pumping lightweight concrete through boreholes drilled from the surface. Although the Hagan project revealed additional problems for subsidence-related coal mine closure, the placement of lightweight concrete by pumping it from the surface into underground grout bags was considered successful.

Between 1983 and 1985, a research project at the USBM's Spokane Research Center, Spokane, WA, investigated the use of lightweight concrete (*6*) as an innovative concept in deformable concrete lining systems underground. This use could aid mine operators by decreasing capital and maintenance costs, increasing the available space in underground haulageways, and providing productivity gains in soft, caving, squeezing, or rock-burst-prone ground conditions often found in deep mines. Research involved using a structural-grade lightweight concrete in the density range of 75 to 125 lb/ft^3 as permanent support in tunnel-type openings, such as haulageways, and nonstructural-grade lightweight concrete in the density range of 25 lb/ft^3 as crushable (frangible) liners. Extensive tests of these materials in both an underground mine and in the laboratory were successful. It was partially the result of this research that allowed the USBM to participate in the present demonstration of lightweight concrete in West Virginia.

Continuing AML research meets the national goal of developing appropriate methods and procedures for sealing mine shafts, adits, and similar openings acceptable to abandoned mine land requirements (*7-11*). A broader project objective was to develop agreement within the engineering community on the research methods needed to close mine shafts under the provisions of PL 95-87.

TEST SITE

During the preliminary site reviews with WVDEP representatives, attention was focused on the southern coal fields of West Virginia. It was determined that the mines in Logan County and adjacent counties were representative of abandoned mine conditions in the state. The site selected is known as the No. 22 shaft and is about 5 miles west of Omar, which is about 12 miles southwest of Logan (fig. 1). This site is listed on the WVDEP inventory as site WV-3231. The shaft had been abandoned since about 1968, according to local sources. It was about 300 ft deep, approximately 10 by 10 ft in cross section, and had a reinforced concrete collar that extended about 30 ft below the present ground level. The shaft was connected to extensive underground workings in the Lower Cedar Grove Seam. This prominent seam has been mined in Logan County since the turn of the century (*12-14*). During the initial site investigation, it became obvious that the No. 22 shaft had been used for water pumping because remnants of pumping equipment were still in place on the surface (fig. 2). However, the deteriorated condition of the concrete collar and the regrowth of vegetation around the site made true assessment of shaft details difficult (fig. 3).

Also noted was that the shaft site was within 50 ft of Pine Creek, which had provided a convenient discharge point for water pumping during the mine's life, and now presented a source of seepage. When the water pumping equipment on the surface was removed, the pump lines and shafting were found within the shaft and these too had to be partially removed (at a contract cost). A description of the coal mines of Logan County in 1965 (*15*) stated that the quantity of water pumped from the mines around Holden, WV, averaged over 1 million gallons per day with pumps as large as 300 horsepower being used.

All field work by the USBM at the No. 22 shaft was done under a memorandum of agreement with WVDEP. Active design work under the guidance of Triad Engineering, acting through a separate contract with WVDEP, provided final contract bid drawings and specifications (*16*) according to USBM design criteria. A pre-bid contractor's meeting was held at the test site on December 13, 1991.

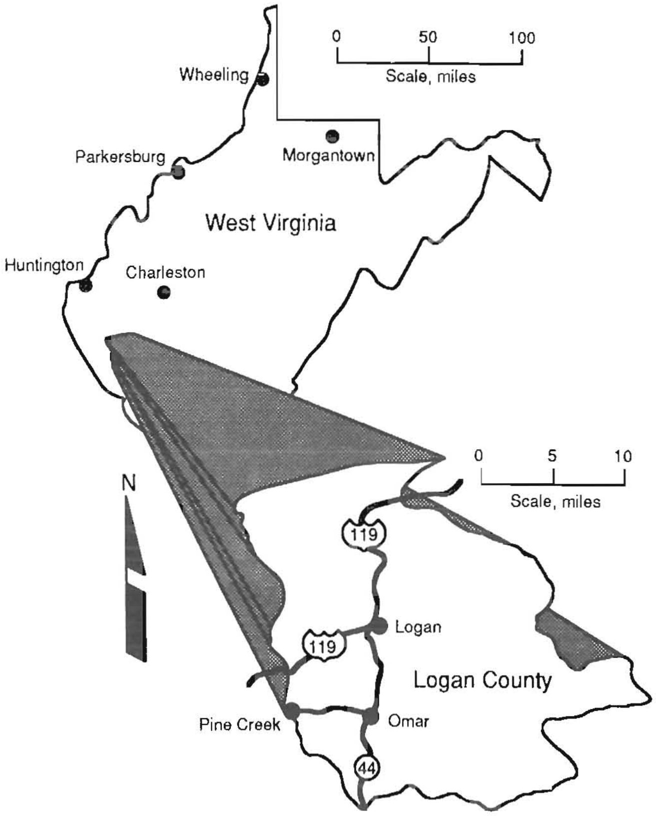

Figure 1.—Location of test site.

Figure 2.—Shaft site. Remnants of pump housing lie over abandoned shaft.

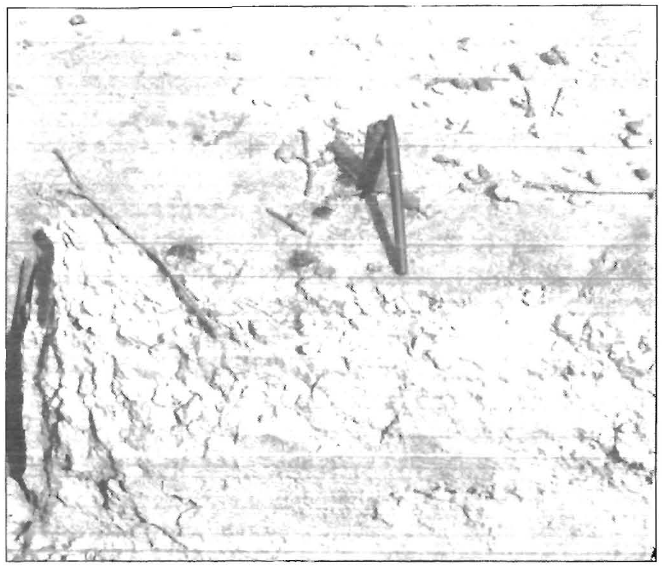

Figure 3.—Deteriorated condition of surface concrete at shaft collar.

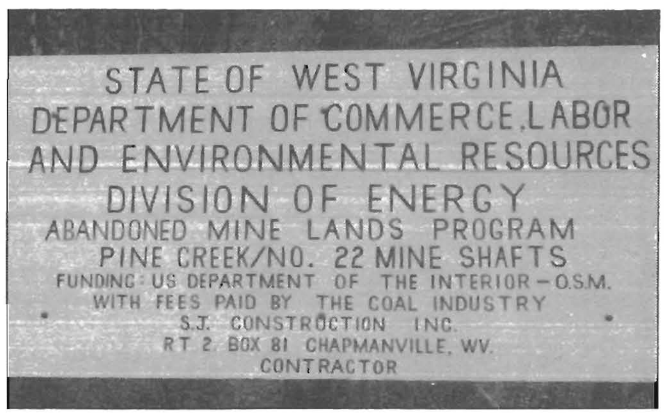

Figure 4.—State of West Virginia construction site identification sign.

Subsequent competitive bidding was held by WVDEP, with the bid being won by S & J Construction of Chapmanville, WV (fig. 4). The actual start date of construction was March 9, 1992. Further delays in construction were allowed because of inclement spring weather.

The USBM was, as were all participants in this work, especially concerned with potential hazards around an abandoned mine shaft. The possibility of significant amounts of methane, especially within allowable explosive limits for methane, was of foremost concern. Provisions for methane testing were written into the contract along with general safety provisions. Methane tests were conducted by WVDEP and by the contractor at various stages of construction as directed by the USBM.[4]

Safety lines were required for all personnel working around the open shaft. The shaft site was covered over each evening and during the weekend as a precaution to prevent access by the general public. Hazard warning

[4]The importance of methane testing in the contract's safety provisions was reinforced during this project by a methane explosion at the Blackville No. 1 Mine in northern West Virginia on March 19, 1992. Four fatalities occurred during abandonment of this mine site.

signs were placed on the county road at appropriate approaches to the shaft. A local security guard was hired to watch the site between sundown and sunup. The local OSM office at Logan inspected the site at least twice.

Operation of heavy equipment in proximity to the collar of the open shaft was of concern initially and noted in the safety provisions of the contract. However, an exceptionally thick concrete collar was revealed during construction and was found to be in very good condition, which reduced hazards from caving around the shaft. Other abandoned mine shafts not having an adequate collar could pose a serious safety hazard and that hazard should be recognized.

DESIGN CONSIDERATIONS FOR NO. 22 SHAFT

A primary design objective was a shaft seal with a design life of at least 100 yr. Many factors other than the primary shaft seal design were, therefore, considered. Presently, active surface coal operations are mining multiple seams about 3 miles west of No. 22 shaft. The railroad along Pine Creek servicing these mines carries at least two 100-car coal trains per week (fig. 5). The county road adjacent to the shaft site is also heavily traveled, and large mining equipment, often requiring the use of an 18-wheel trailer, is hauled on it.

To satisfy the goal of a 100-yr life, it became necessary to review possible future mining events. The most extreme scenario is that the valley could be filled with mine refuse, as has occurred in a spur valley to Pine Creek about a mile upstream. A less severe possibility is that the railroad may realign its right-of-way and cover the present shaft site, or the county may improve and regrade the present road between the shaft and the railroad to accommodate future mine development. Underground mining may also be restarted with reentry to the Cedar Grove Seams or by mining deeper coal seams, such as the Pocahontas Seam, which might be present in this area.

Figure 5.—Railroad and county road traffic along shaft site. Shaft cover is being prepared as safety precaution.

More recently, a major natural gas exploration program has been underway in Logan County. The drilling objective is the Devonian Marcellus Shale at about 4,800 ft. One well has been drilled about 0.5 mile to the east of No. 22 shaft, and another was drilled on an abandoned mine site about 1 mile to the southeast. West Virginia is a leading producer of natural gas, as well as coal, and the drilling of gas wells over abandoned coal mine sites must be considered in any mine abandonment plans in West Virginia.

Because of the proximity of the shaft to Pine Creek, concern was expressed for dangers that might result from a 100-yr flood along Pine Creek. The maximum topographic relief in the upstream drainage of Pine Creek is over 900 ft between the valley floor of Pine Creek (1,020 ft) and the adjoining ridgeline to the northwest (1,932 ft). Topographic maps were reviewed, and the watershed above Pine Creek to the west was determined to be about 2,317 acres, or 3.62 square miles. This extensive drainage is perhaps typical of a small stream in the mountainous topography of southern West Virginia. In addition, maximum rainfall intensity maps of the U.S. Department of Agriculture were consulted. No doubt a flood of considerable magnitude could occur and sweep down Pine Creek, with devastating results. All of these possibilities were considered by the USBM in determining relevant factors for a 100-yr design life of a shaft seal.

Also considered was runoff from upstream coal mines and refuse piles and acidic mine water from other abandoned mines (resulting from sulfate or pyrite minerals). Concern was expressed about the possibility of sulfate attack on the concrete within the seal. Of lesser concern was the possible effect of biological factors, such as the leaching of humus or overly fertilized soils, resulting in harmful concentrations of humic acids or ammonium nitrate, which can affect the long-term durability of concrete. Even such seemingly innocuous effects as the dissolution of atmospheric carbon dioxide in water can produce a weak carbonic acid solution that has been found to affect the long-term durability of concrete (a problem in large cities with buildings faced with natural stone).

GENERIC DESIGN CONSIDERATIONS

Little or no precedence for designing mine shaft closure is available for mines in the United States. The most pertinent reference is the 1982 publication of the National Coal Board (NCB) of Great Britain, "The Treatment of Disused Mine Shafts and Adits" (*17*). This NCB publication provides general guidelines for abandonment of shafts regardless of specific circumstances.

Essentially, the three principal methods discussed by the NCB are (1) completely backfilling the shaft, (2) placing an internal concrete plug in the shaft at some depth, and (3) covering the shaft with a reinforced concrete cap. All three methods present installation and long-term stability problems, depending on individual site conditions. Simple backfilling of the shaft is subject to later settling and the possible creation of voids caused by bridging during filling. An internal plug at depth may be difficult to install, as well as posing construction hazards to those personnel required to enter the shaft. Keying the plug into the old shaft or to bedrock could also present problems, depending on specific shaft conditions. Concrete caps are subject to later shaft caving and possible surface collapse beneath the soil, which may undermine the stability of the cap. Also, an unsupported concrete cap over an open shaft will sustain increased bending stresses with possible loss of stability in the future.

Two criteria taken directly from the NCB publication for this project were the recommendations that a live load of 5 psi be used for a heavy-duty shaft seal and that the shaft be sealed to a depth of at least one shaft diameter.

Past practice for shaft closure in many cases has been found to be haphazard, as was shown by the original abandonment of the No. 22 shaft. Randomly placed steel and timber gratings, prefabricated covers, and salvaged steel or timber beams laid over the shaft have all been used in the past. Many shafts are simply filled with local materials, or covered without regard to engineering principles or future consequences. None of these "methods" can be considered an engineered design within the intent of the Surface Mining Control and Reclamation Act.

A number of alternative designs were developed for support of the seal, including support by an outer footing with drilled piers or by keying a slot into the existing shaft walls at some point down the shaft. A point worth noting is that old shaft walls may offer limited structural support at best. This was certainly the observation when the No. 22 shaft was first examined and the deteriorated condition of the shaft became obvious (fig. 3). Even if a shaft has been fully lined with concrete, the condition of the original lining cannot always be guaranteed. Voids or weak strata may be adjacent to an abandoned shaft and could cause the shaft to collapse under load. Therefore, a permanent mine seal should not rely on support from an existing shaft liner. A permanent mine shaft seal should be based on an engineered design with footings, slots, or keyed openings cut into known competent strata.

Aspects of concrete technology pertaining to concrete sealants, waterproofing, and durability were included in the specific design features and contract provisions for this project, although it is acknowledged that concrete sealants and waterproofing agents are a continuing research field (*18-20*). The use of silica fume, or microsilica (to decrease permeability), water-reducing agents (to reduce the water:cement ratio), and Type II cement (to increase resistance to sulfate attack) were specified for the lightweight concrete. Water-reducing agents, air-entraining agents, and fly ash were added to the normal-weight concrete. Fly ash is a by-product from coal-fired power plants and compliments the funding source for AML projects (*21-22*). Chloride-free concrete additives were specified in the contract. Low water:cement ratios were used to increase durability. However, materials that might be considered objectionable from an environmental standpoint, or that would introduce materials more objectionable than those already at the site, were excluded.

The primary sealant and waterproofing material selected was one familiar to the coal industry and approved by the Mine Safety and Health Administration (MSHA) for flexural and flame-spreading resistance. This material is based on sodium silicate chemistry and fiber reinforcement. The manufacturer agreed to conduct an acid resistance test using various concentrations of sulfuric acid (as strong as 25% by volume). Laboratory results were favorable. The fiber reinforcement gave the material sufficient flexibility so that temperature expansion and contraction had little or no effect on cracking. This sealant was applied to those shaft structural elements requiring waterproofing.

Previous USBM research in lightweight concrete (*6*) was reviewed for specific application to mine sealing (*23-25*). Questions concerning the relevant properties of lightweight concrete, such as durability, effects of possible freeze-thaw cycles, resistance to acidic coal mine waters, use of additives (including silica fume to decrease the permeability of concrete), and agents to enhance bonding with the shaft walls were all investigated.

The basis for selecting a wet density of 45 lb/ft^3 for lightweight concrete was based on prior USBM experience and design analysis. This density represented a trade-off between the amount of material to be supported by the downshaft platform and the strength expected to be mobilized for shaft sidewall support. These material requirements were not severe. A density greater than 25 to 35 lb/ft^3 but less than 50 to 60 lb/ft^3 was deemed adequate.

As part of the broad generic investigation of shaft seals, USBM representatives visited the concrete divisions of the Bureau of Reclamation, Denver, CO, and the U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS, to study concrete durability and to gain expertise in concrete technology. In addition, World of Concrete symposia were attended to determine the extent of the industry's expertise in similar construction problems. Importantly, new developments in the technology of concrete additives, such as accelerators, water-reducing agents, and improvements in concrete durability, were noted. Research in surface concrete sealants funded by various state departments of transportation and the Federal Highway Administration were reviewed for useful technology applicable to AML problems (*26-27*). Perhaps at no other time in the history of cement and concrete technology has more progress been made and such a wide range of concrete additives been available, particularly in areas suited to the needs of the mining industry.

The MSHA Denver Technical Support Group provided valuable information and design suggestions.[5] The work of the USBM was reviewed at all stages by MSHA Technical Support Group personnel. Applicable standards of the American Society for Testing and Materials (ASTM), American Institute of Steel Construction, the American Concrete Institute (ACI), the ACI Committee 523 on cellular concrete, and others, as necessary, were specified in the bid documents of WVDEP (*16, 28-29*).

Finally, it was also thought prudent to provide a completed shaft seal with an attractive appearance to the public. Shaft seal designs should be compatible with other reclamation projects of WVDEP. Many reclaimed coal mine sites in West Virginia have been turned into public parks, campgrounds, and picnic areas. Therefore, revegetation needs were included in the shaft sealing criteria. The existing WVDEP program in agronomy was most helpful in satisfying the need for an attractive appearance (the cooperative agreement turned the revegetation task back to West Virginia). Abandoned mine seals should provide barriers sufficient to resist vandalism or attempts to gain entry, and, especially for shafts, should provide sufficient load-bearing capacity to assure future safety. Figures 6 and 7 are schematic representations of the No. 22 shaft seal design.

[5]Personal communication and memorandum from M. P. Sheridan, MSHA, dated May 15, 1990.

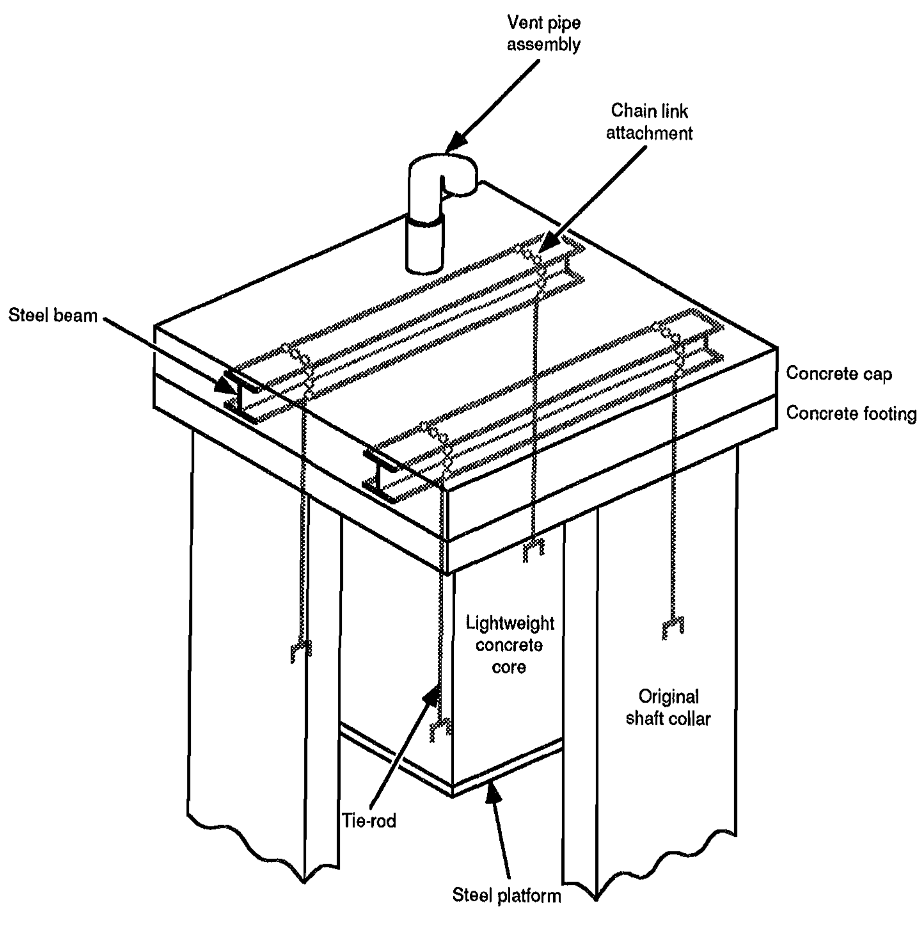

Figure 6.—Structural elements in shaft seal design.

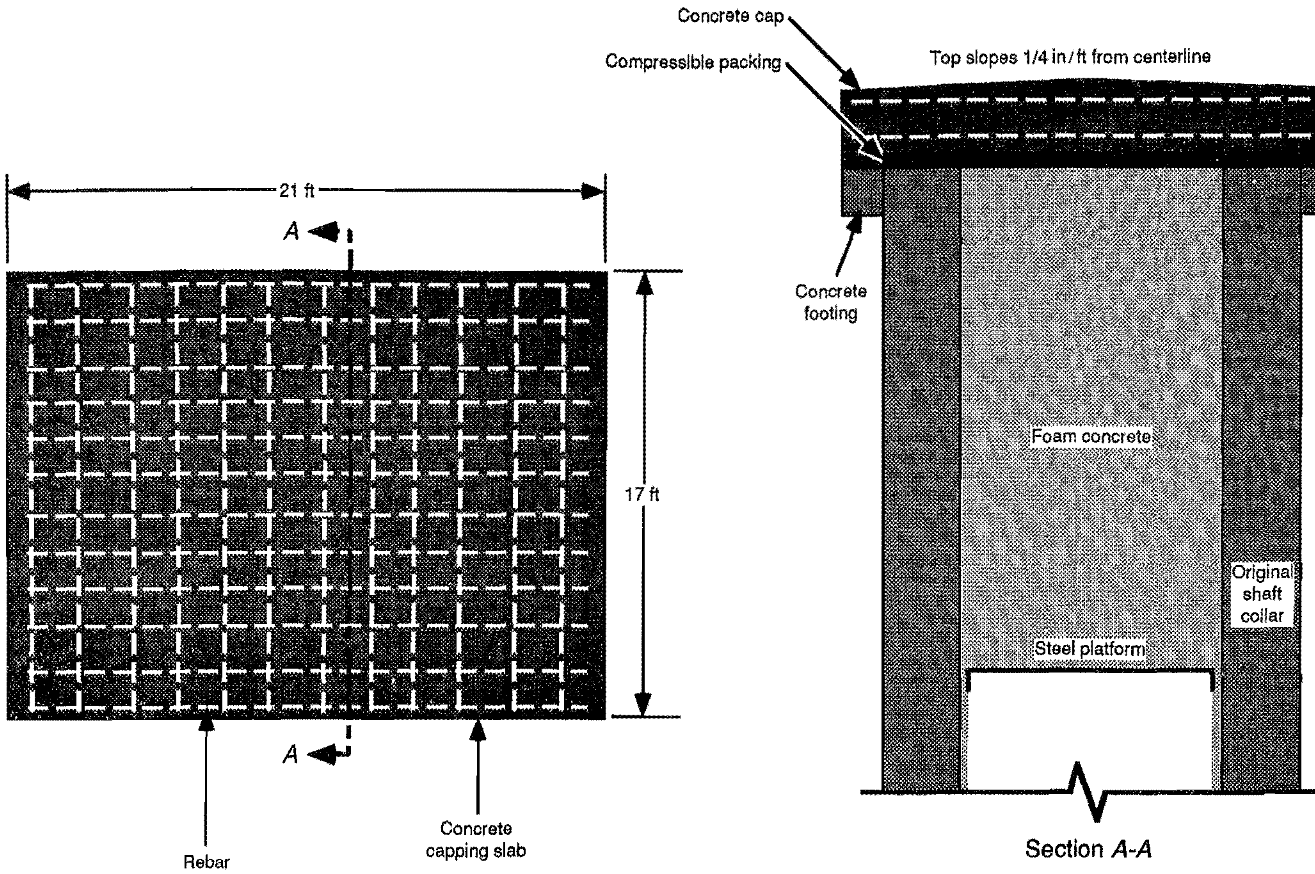

Figure 7.—Cross section of shaft seal.

BASIC WORK TASKS

Upon finalizing the design criteria and completing discussions with all parties concerned, the anticipated construction program evolved into the following tasks. These were included and defined in the contract documents issued by WVDEP (*16*). The importance of a fixed construction sequence was recognized throughout the project. These construction steps became part of WVDEP contract specifications in which the work tasks were set out in sequence, as listed below.

- Explore the shaft site to determine ground conditions and provide other geotechnical information. This work includes test borings and tests to determine load-bearing capacity and the nature, condition, and extent of the original shaft collar.
- Demolish the original reinforced concrete shaft collar to unweathered concrete and remove to a predetermined grade.
- Clean shaft walls by power-washing to restore original surface conditions. The depth of this power cleaning shall be to a depth of 1 ft below the approximate position of the platform to be lowered into the shaft. (This requirement evolved after the initial field examination revealed a thick layer of moss within the shaft.)
- Excavate footings around all sides of the original shaft collar to a specified depth. Unnecessary excavation is not permitted. An additional subbase may also be required. (Because of the proximity of the road, this excavation was not made to the same depth around all sides of the shaft.)
- Compact original soil around the shaft collar to specifications (95% compaction) and provide for surface drainage away from the original shaft collar.
- Coat exposed surfaces of the footings with an approved waterproofing sealant. A two-pass procedure shall be applied to avoid pinholes and cracks developing in the sealants.
- Erect concrete formwork for the footings, including within the areas to be covered by the sealant.
- Place concrete reinforcement for the footings. (The design required No. 6 bars on 12-in centers each way, with the bottom mat 3 in from the ground and the top mat 2 in below the top of the pour.)
- Place concrete for footings according to specifications. Footings shall be cured for 24 h before applying any loads.

- Coat original shaft walls with the same approved coating and two-pass procedure as for the footings, but in increments starting at the bottom of the platform in the shaft.
- Fabricate a steel platform. The platform is to fit inside the shaft dimensions and will be lowered to a minimum depth of one shaft diameter. The steel platform, tie-rods, connecting hardware, and the top steel beam assembly are to be designed to suspend the entire weight of the lightweight concrete core without failing.
- When delivered to the site, paint the steel platform with two coats of corrosion-resistant, industrial-grade paint.
- Wrap the steel platform with a geomembrane that completely covers the platform on all sides.
- Place temporary lifting lines to hold the steel platform in place while it is being lowered into the shaft and until final downshaft connections are made.
- Place two steel beams across the top of the shaft to rest on the footings previously poured. (On this project, these beams were designed for loads requiring two 12 WF 30 beams.)
- Use temporary lifting lines to hold the steel platform in place while the steel beams are being positioned. Permanent hardware shall be connected to the steel platform with attachment to the tie-rods and steel beams being made at this time. Safety lines between the platform and the beams shall then be released.
- Weld spacing bars between the beams to prevent possible overturning of the beams.
- The shaft may then be entered by personnel, the platform centered, and the vent tube readied for placement. The vent tube shall be placed at least 1 ft below the platform and shall extend above the lightweight concrete pour (the platform shall have a suitable cut-out for placement of the vent tube).
- Place strips of geomembrane fabric between the platform and the shaft walls and attach with approved adhesive. Seams shall overlap at least 6 in, and the geomembrane strips shall not be less than 15 in wide. Geomembrane fabric shall extend around the entire inside perimeter of the platform, leaving no open space so as to ensure that moisture from down the shaft or from the surrounding ground is prevented from penetrating the lightweight concrete.
- Coat the shaft walls with the same sealant and two-pass procedure as used previously, but just above the platform and to a height of at least 30 in (for the first lightweight concrete pour).
- Lay a mat of No. 4 rebar on 15-in centers above the platform to rest on the tie-rod supporting members. No welding shall be permitted within the shaft.
- Place an upper mat of No. 4 rebar on 15-in centers above the bottom mat and at a distance so that the upper mat will be at least 2 in below the top of the first lightweight concrete pour.
- Place lightweight concrete in the shaft. (The design for this project allowed a depth of lightweight concrete equal to one shaft diameter minimum in accordance with recommendations of the NCB. The platform and beam assembly were designed to support the wet weight of the entire lightweight concrete pour. It was decided to break this volume into separate pours, each about 10 yd^3, with special attention being given to the first pour to ensure that no leakage occurred and to allow exothermic heat to dissipate. Successive pours were to be made in increments, with up to a maximum of 24 h between pours.[6]
- Continue applying waterproofing sealant to the inside shaft walls just before each lightweight concrete pour. The objective is to provide a fresh sealant that is not fully hardened and that will bond itself to the wall and to the lightweight concrete. The time interval between application of the sealant and the lightweight concrete shall be no more than 1 h.
- Coat the top surface with waterproofing sealant upon completion of the lightweight concrete pours to a level just below the steel beams using a two-pass procedure as before.
- Cover the area beneath the steel beams and enclosed within the footings with a layer of compressible packing material. The purpose of the compressible material is to allow for possible future movement between the lightweight concrete core and the concrete cap, or combinations of movement.
- Construct concrete formwork for the reinforced concrete cap.
- Place double mats of rebar for the reinforced concrete cap. (To handle the design loading of 5 psi, the primary bottom rebar was No. 8 and the top rebar was No. 4. Both primary mats were on 12-in centers. The secondary bottom rebar was No. 5 and the top rebar was No. 4 on 15- and 12-in centers, respectively. Other design loads would have different rebar specifications.)
- Pour concrete for top slab. The thickness shall be 16 in at the edges and 18-1/8 in at the center. The slope of the top surface shall be 1/4 in/ft. To allow proper water runoff, it is important to maintain thickness and slope. Depth of concrete over the steel beams shall be at least 4 in and concrete over the top rebar shall be at least 2-1/2 in. The distance from the ends of the steel beams to the outer edges of the concrete footings shall be 6 in.

[6]Of course a thicker lightweight concrete pour could have easily been made, but that would have increased the need for greater platform and connection strengths between the platform and the supporting beams. A design trade-off was necessary. Design considerations focused on a lightweight concrete having a wet weight in the range of 45 lb/ft^3 and a compressive strength of at least 100 psi. With approximately 10- by 10-ft shaft dimensions and a pour depth of 10 ft, the total wet weight of the lightweight concrete would be about 45,000 lb.

- Apply suitable concrete sealant to the top surface of the concrete slab to ensure long-term durability. The preferred material is a polymer coating similar to that applied on concrete bridge surfaces (*26-27*). Manufacturer's specifications shall be followed in applying the sealant.
- Care shall be taken not to load the slab until at least 7 days following the pour, and preferably not for 28 days, for a load approaching the design load. Direct-wheel loading shall not be allowed for at least 28 days.
- Revegetate the site according to specifications. Erosion and sediment control measures shall be taken along stream banks, if necessary. The entire shaft site shall be regraded and approved topsoil placed over the shaft to a specified depth. Seedbed preparation, liming, and fertilizing are to be done as in prior practice in West Virginia as directed by the project engineer.

DESCRIPTION OF CONSTRUCTION METHODS

GEOTECHNICAL INVESTIGATIONS

At the request of the USBM, WVDEP authorized preconstruction site investigations by Triad Engineering. Site drilling revealed that fill materials existed to a depth of approximately 10 ft. Bedrock was encountered at depths of 10 and 15 ft in the two holes drilled. Ground water was encountered at a depth of 6 to 7 ft and probably was seepage originating from Pine Creek, less than 50 ft away. Load-bearing tests confirmed that the natural and fill materials were suitable for support of foundations designed for an allowable bearing capacity of 1,000 lb/ft^2 as determined from standard penetration tests. No further site investigations were conducted, although the water of Pine Creek was later tested for pH and hardness to determine its suitability for making lightweight concrete on site.

SHAFT COLLAR REMOVAL

As mentioned, initial inspection of the No. 22 shaft site revealed the deteriorated condition of the surface concrete and the extraordinary amount of vegetation regrowth (figs. 2-3). Construction required that the original concrete cap and concrete collar be removed, and both were ultimately excavated to a depth about 2 ft below the initial collar height.

Because the contract allowed no explosives to be used, and the contractor did not have suitable equipment, all demolition was done with pneumatic hand-held jackhammers. This manual work extended throughout the better part of a week, and often personnel had to operate jackhammers along the edge of the shaft. Therefore, safety lines were required of all personnel. Methane testing was also required.

It was only after the collar was fully exposed that details of the original shaft construction could be determined. It was found that the walls were 24 in thick east-west and 30 in thick north-south and were reinforced with inner and outer rebar[7] cages on approximately 10-in centers (fig. 8). The shaft collar had evidently been set on bedrock at a depth of about 30 ft. The remainder of the shaft was unlined and was without visible ground support.

SHAFT UTILITIES REMOVAL

Surface remnants of the original pump housing, including the attached shaft utilities, were in place at the start of this project (figs. 2, 9). The surface-mounted electric motor frames were attached to pump lines that extended throughout the entire vertical length of the shaft. One line lay on each side of the shaft and consisted of a 12-in-diam steel pump line with an inner 3-1/2-in-diam solid steel shafting of hardened steel. A buried electrical line was also discovered during excavation for the footings.

[7]This rebar was a type known as Ransome rebar. It was fabricated with a twisted section and was typically used until the 1920's.

Figure 8.—Removing original concrete shaft collar with jackhammer.

Removal of shaft utilities was done in two stages: the removal of surface equipment and debris, and the cutting away of pump lines and shafting within the shaft to a depth of approximately 12 ft below the collar. No materials were salvaged. Removing the shaft utility lines was completed in conjunction with the removal of the concrete collar (fig. 10) and was extremely hazardous.

SHAFT COLLAR PREPARATION

The true deteriorated condition of the original shaft was obscured by a thick layer of moss and other plant growth around, and particularly within, the shaft, and resulted from the moist, warm air coming from the mine workings below.

A subcontract to a commercial power-washing company provided personnel and equipment for washing the walls of the shaft collar to about 12 ft below the collar. Approximately 300 gal of water at 240° F and 1,500 psi was used. The task was completed within 3 h. Visual inspection of the washed shaft revealed remarkably little concrete deterioration at depth and showed that the concrete below the shaft collar was in good condition.

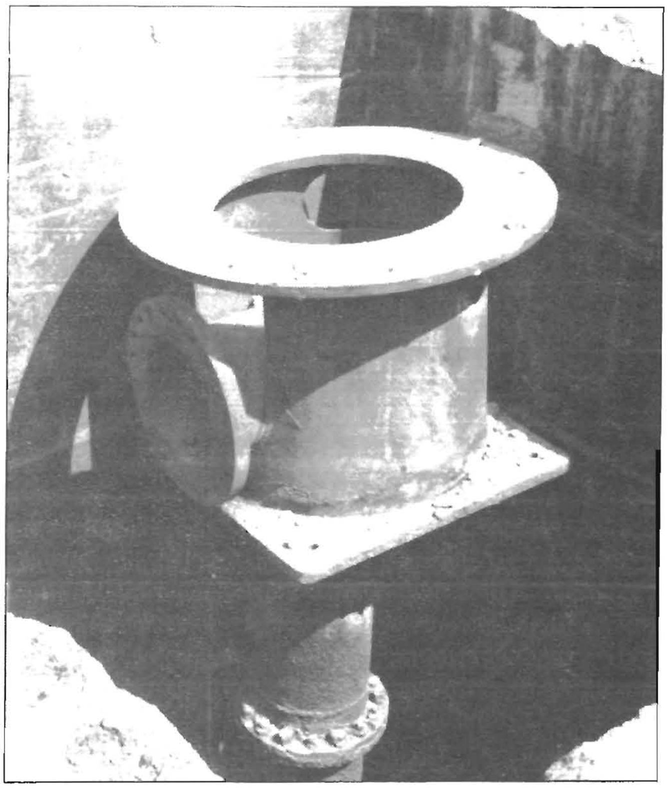

Figure 9.—Shaft pump housing just below collar of demolished surface concrete.

FOOTINGS

Formwork and Rebar

Concrete formwork was simplified by removing the original concrete collar to about road level. This avoided unnecessary excavation and construction. Footings formworks were 12 to 15 in deep and 15 in wide along the north-south edges and 4 ft wide along the east-west edges and were easily assembled from 2- by 8-in lumber. It was preferred that footing dimensions be equal all around but closeness to the road prevented implementation of this design.

Double mats of No. 6 rebar were placed in all footings. The east and west footings, being wider, had top and bottom mats of No. 6 rebar on about 14-in centers lengthwise and 10-in centers across. Footings along the north and south edges, being smaller, had mats of No. 6 rebar on 4-in centers lengthwise and 12- to 15-in centers across. All connections were tied with wire because no welding was permitted around the open shaft. Because the shaft dimensions were different than anticipated, some pieces of rebar had to be cut in the field for the footings.

To prevent groundwater seepage and protect the shaft core, the program of using waterproofing sealants was begun upon construction of the footings. Celtite 10-14[8] waterproof sealant was applied to all exposed surfaces, including the ground. Six 5-gal buckets were applied to the footings alone. At the contractor's suggestion, and expense, sheets of mine brattice cloth[9] were laid on the ground surface to overlap with the original shaft collar and extend beyond prepared footings. This idea should be expanded for future AML work where acid mine waters are present.

Concreting of Footings

Access to the shaft site from the nearby road allowed ease of concrete placement. Concrete mix was obtained from a ready-mix supplier at Logan. Approximately 7-1/2 yd^3 were placed within about 1 h. No difficulties were experienced with this pour. Further details on mix design and materials testing is included in the section on Reinforced Concrete Surface Seal.

[8]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

[9]The manufacturer of this particular mine brattice cloth stated that it contains a flame-resistant polyester material over a scrim of nonwoven webbing on 3- and 7-mm centers. By contrast, the geotechnical fabric selected for this project was impregnated with chlorosulfonated polyethylene (a synthetic rubber) and contained fully woven thread cross-stitched on 2-mm centers.

Figure 10.—Removing shaft utilities after removal of shaft collar.

CORROSION PROTECTION AND WATER SEALING

After the original shaft walls had been power washed, a coating of Celtite 10-12 waterproofing sealant was applied to the lower surfaces of the shaft walls in 2-ft increments across the projected depth of the platform (fig. 11). A similar coating was applied to the shaft walls just before each lift of lightweight concrete, preferably within 1 h before placement, then over the entire top of the lightweight concrete, including the surface perimeter of the original shaft and inside the new footing walls. Coatings applied within the shaft were applied with a roller-brush and an extension handle. This lessened the necessity of working within an open shaft. In simple field tests, the Celtite 10-12 waterproofing sealant appeared to dry quickly and bond well to other materials. All subsequent waterproofing used Celtite 10-12 waterproofing sealant.

The objective of the waterproofing treatment was to waterproof all exposed surfaces of the footings and especially to coat the perimeter of the central lightweight concrete core to provide as much corrosion and waterproofing protection as possible.

Every steel member in the structure was painted with two coats of corrosion-resistant, industrial-grade paint. All rebar was epoxy coated. Rebar that had to be cut in the field was repainted with epoxy.

Hypalon geomembrane sheeting was wrapped around the steel platform to enclose the platform completely. Seams in the Hypalon were sealed with a manufacturer-approved sealant. Hypalon was selected as the best all-around material for these conditions. High-density polyethylene was also considered, but its flammability in an underground fire during construction of the Los Angeles Metro was noted (*30*). Additional applications of corrosion-resistant and water-resistant sealing materials will be described as appropriate.

SHAFT PLATFORM AND INSTALLATION

When the internal shaft became fully exposed after the original concrete collar was demolished, precise shaft dimensions could be used to fabricate the shaft platform. The platform dimensions were made about 2 in less all around than the internal shaft dimensions to allow an easy fit. The platform was fabricated at a local machine shop with continuous 4 WF 13 beams as the main framing members and cross-stiffeners. Angles of 4 by 4 by 1/2 in framed the perimeter of the beam members, and 5/16-in steel plate was welded over the entire assembly. The bottom surface was not covered with steel plate. Four, short, 4- by 6- by 1/2-in angles were welded on the top of the platform to attach the tie-rods. All members were

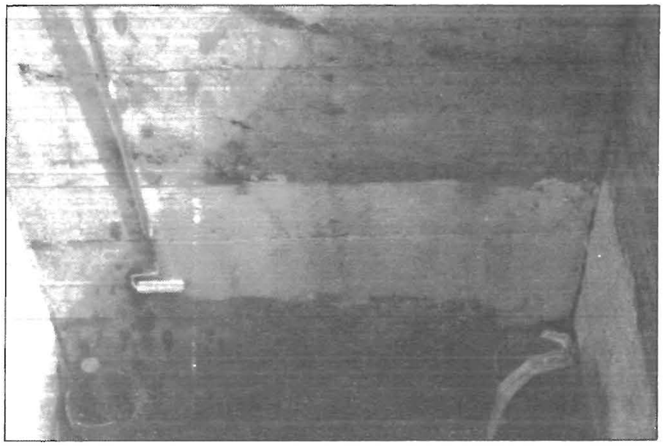

Figure 11.—Applying waterproofing coating. This was done after original shaft walls had been power washed and shaft utilities removed.

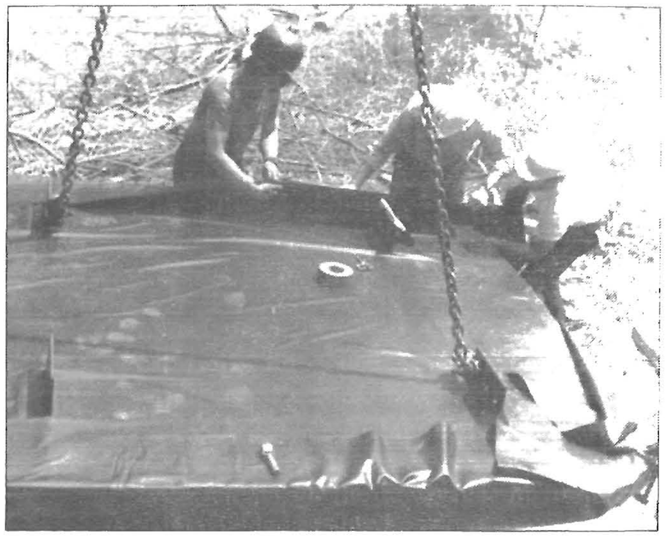

Figure 12.—Applying geomembrane covering to shaft platform.

welded throughout. The reported shipping weight of the platform and attachments was 2,550 lb. Basic design criteria were that the platform assembly would support the entire wet weight of the lightweight concrete.

The platform was painted in the field with two coats of corrosion-resistant, industrial-grade paint before wrapping with Hypalon geomembrane. The Hypalon fabric was supplied in one large sheet for the bottom wrap and a smaller sheet for the top wrap. Strips of Hypalon were used to seal the joints between the platform and the shaft walls. Manufacturer-approved glue was used on all joints (fig. 12). Wrapping and sealing the platform with geomembrane in the field was considered very successful (fig. 13).

The platform was suspended from the angle plates welded to the platform with 1-1/4-in-diam tie-rods near each of the four corners. On the surface, double 12 WF 30 beams 20 ft long were laid across the concrete footings on 5-ft centers with rebar welded between the beams on each end. To simplify field construction, the tie-rods to the beams were attached through a length of 3/4-in, NACM grade 43 chain with appropriate clevis and Lok-A-Loy connecting link[10] (fig. 14). The chain provided more flexibility in making adjustments and allowing for differential movement.

After covering the platform with the geomembrane, the platform was moved to the shaft, the tie-rods and chain were attached, and the entire assembly was lowered into the shaft without incident (fig. 15). Adjusting the chain positions on the beams, so that the weight became equally distributed, completed the installation. Within the shaft,

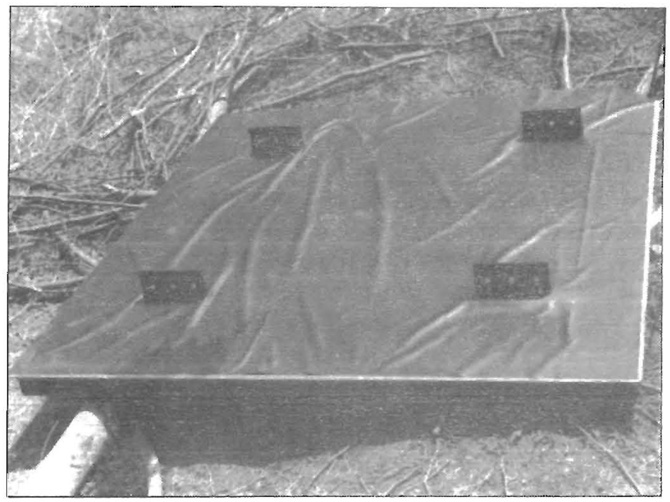

Figure 13.—Shaft platform wrapped with geomembrane.

short pieces of Hypalon were glued to the shaft walls and overlapped onto the platform and also glued. The platform was blocked with 2 by 4's wedged to the angles welded onto the platform. This also served to center the platform in the open shaft.

Number 4 rebar was placed on 15-in centers and rested on steel washers placed through the tie-rods at the platform connections. A top mat of No. 4 rebar was similarly placed approximately 28 in above the platform deck. No additional reinforcement was used within the lightweight concrete pours. All rebar connections were tied with wire by hand because no welding was allowed in the shaft.

All tasks associated with the downshaft platform assembly were completed as planned. At this stage, pouring the lightweight concrete in the shaft could begin.

[10]It is recognized that chain could have been used for the complete assembly between the beams and the platform. Chain may have the additional advantage that connection components have manufacturer-certified strengths.

PLACEMENT OF LIGHTWEIGHT CONCRETE

The demonstration of lightweight concrete was the featured material in the USBM's proposal. However, because of the remote location and the small quantity of concrete involved (37 yd^3), selection of a suitable lightweight concrete supplier became more difficult than expected. After negotiation with several suppliers, the proposal of Elastizell Corp. of America was accepted. The USBM design criteria were that the wet field weight should be in the range of 45 (-5 or +4) lb/ft^3 and that the 28-day compressive strength should be at least, and preferably exceed, 100 psi. These criteria were subsequently included in the bid proposal package by the WVDEP (*16*, pp. 12-13).

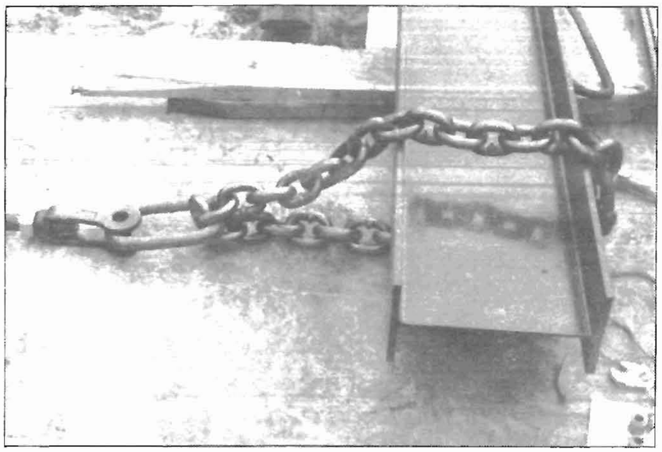

Figure 14.—Assembly mock-up showing beam, chain, clevis, and attachment to tie-rod on platform.

Elastizell Corp. equipment consisted of a unitized mixing and pumping truck and a supporting truck that carried raw cement. The pumping truck was designed to make a continuous mix at quantities up to 50 yd^3/h (fig. 16). Mix water was taken directly from Pine Creek (after Elastizell Corp. had submitted a laboratory sample for water-quality testing). An inclined auger fed cement from a truck-mounted storage bin to a temporary weighing bin where the amount of cement was measured on an electronic scale. The cement was then augered to a mixing hopper where water, also measured on an electronic digital flow meter in gallons, was added and the mix agitated within a closed, horizontal paddle mixer at 60 rpm. After approximately 30 s of mixing, foaming agent was added by a timer circuit (for this mix design the time was 34 s at a water-foam ratio of 40:1), and the resulting slurry was mixed for about 2 min. Mix additives were added manually through a door in the top of the mixer. The slurry was then gravity fed into a holding tank from which it was pumped by Moyno pump through a 120-ft length of 2-1/2-in-diam rubber hose with Victaulic couplings at a pumping pressure of 20 to 25 psi. All mix operations were controlled by a single operator. In operation, mixing was

Figure 15.—Platform being lowered into shaft. Note beams in place alongside shaft.

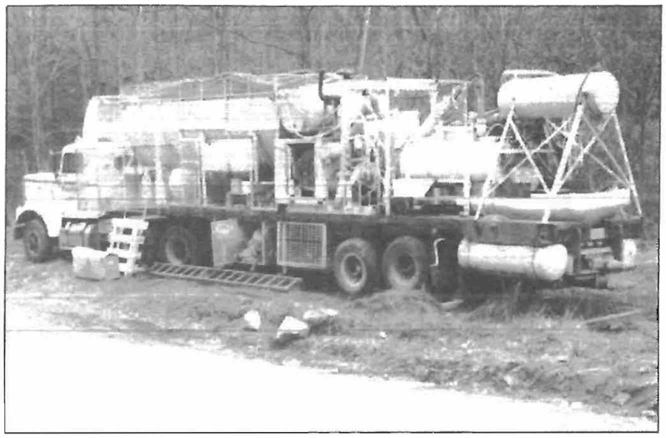

Figure 16.—Truck-mounted equipment for mixing and placing lightweight concrete.

nearly continuous, and at no point was the capacity of the contractor's equipment reached.

The mix design submitted by Elastizell Corp. was as follows:

Ingredient	*Amount*
Cement, Type II	720 lb
Water, 35.62 gal	296.7 lb
Foam, timed 34 s, 40:1 mix	18.62 ft^3
Superplasticizer	1 qt/yd^3
Microsilica, 6.5% by wt	50 lb/yd

The calculated wet density was 45 lb/ft^3 with a water:cement ratio of 0.41.

No deviation from this mix design was made by the contractor other than minor adjustments in wet weight. The superplasticizer was cut back to 1/2 qt/yd^3 and discontinued after the first pour because of the short pumping length. The silica fume (microsilica) was added manually at the mixing drum for all pours. The effect of the silica fume in increasing mix viscosity was only partially observable. The addition of silica fume decreased the water:cement ratio slightly, from 0.41 to 0.386.

After the cement was pneumatically off-loaded from the supporting cement truck, the first pour was completed within 1 h to a depth of 33 in. Twelve batches were mixed for this pour. Wet weight samples were taken, and corrections were made quickly at the mixing truck (figs. 17-18).

Because of the success of the first pour early in the morning, a second pour was scheduled for late in the day. The second pour of 13 batches was also without incident, coming nearly exactly on the target (wet) unit weight and to the required depth. However, to flush the mixing hopper and the pump lines, the additional mix was added to the second pour, which reached 52 in total depth.

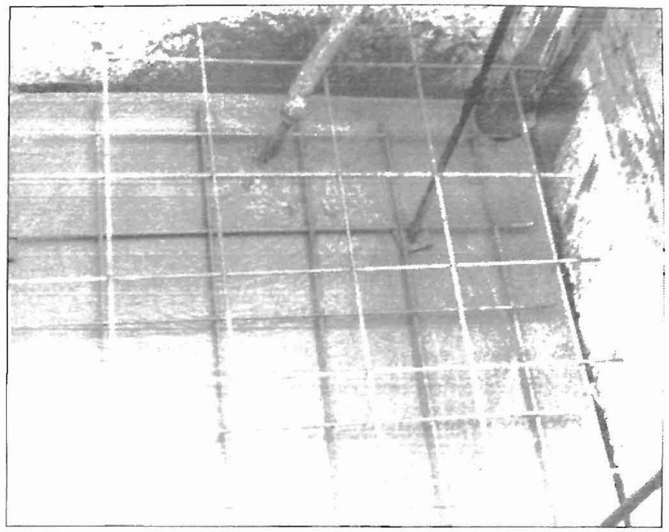

Figure 17.—Start of lightweight concrete filling of shaft. Note bottom rebar cages.

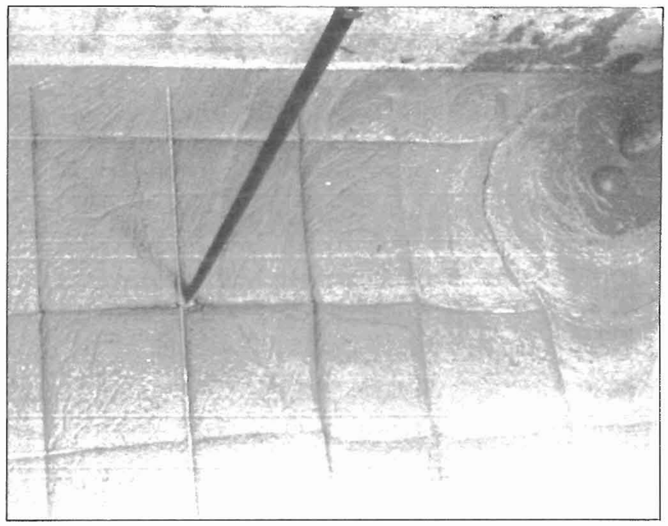

Figure 18.—First pour of lightweight concrete up to level of top rebar cage. Note texture of flow by slight depression of rebar as lightweight concrete covers rebar.

The next morning, the remaining shaft walls were roller brushed with Celtite 10-12 waterproofing sealant, and the final 42 in was filled with 11 batches (figs. 19-20). A final 12th batch was added to flow over remnants of the original shaft walls (fig. 21). All lightweight concrete pours were completed by noon of the second day. All aspects of the lightweight concrete pumping operations were satisfactory.

The following morning, the top surface of lightweight concrete was roller brushed with Celtite 10-12 waterproofing sealant, and the compressible packing was placed.

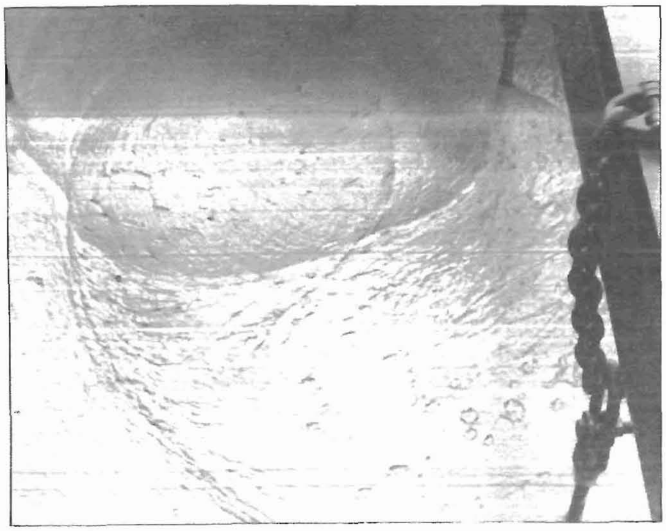

Figure 19.—Texture of lightweight concrete in third pour.

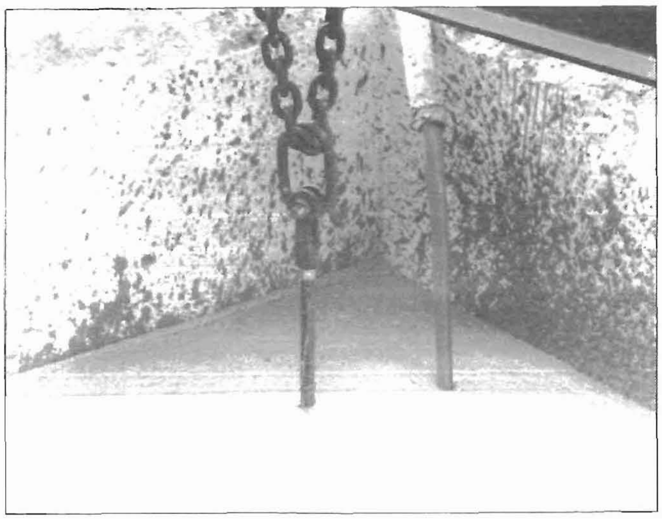

Figure 20.—Lightweight concrete near top of shaft collar. Note chain and clevis assembly with tie-rod.

Because of the exceptionally high cement content (720 lb/yd^3) used by the contractor, the lightweight concrete mix became more exothermic than expected. This was first noted the morning after the second pour when visible steam was seen rising from the partially cured surface, particularly around one of the tie-rods. However, no surface cracking was evident. After the third pour, the surface temperature was monitored for approximately 6-1/2 h. The maximum temperature reached was 117° F, at which time the thermometer was over-ranged.

The next morning, the temperature had dropped to 106° F. These temperatures were all surface temperatures recorded under a blanket of scrap Hypalon. Following placement of the compressible material over the lightweight concrete, the temperature increased to 110° F. Just

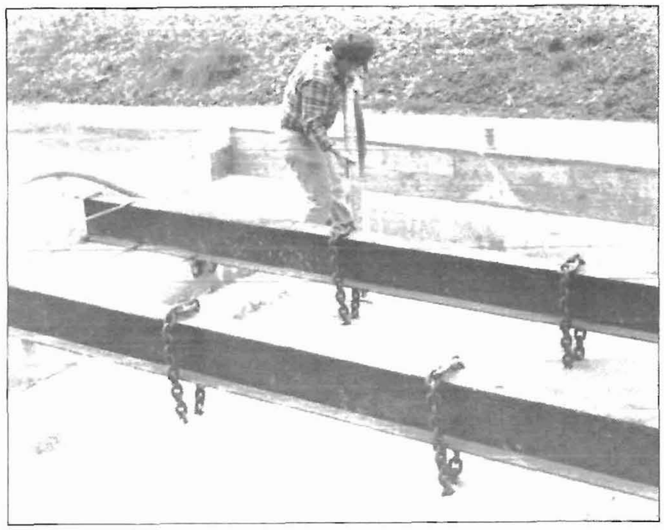

Figure 21.—Completion of lightweight concrete pours to top of shaft collar and just below steel beams.

before the concrete was placed for the top seal, the temperature under the compressible blanket was 97° F, which was 46 h after the final lightweight concrete had been placed. The main cap seal was then placed without incident, and negative effects of high temperatures in the lightweight concrete were not expected.

COMPRESSIBLE PACKING

At the conclusion of the lightweight concrete pours, a layer of compressible packing was laid over the lightweight concrete and beneath the steel beams. Although a specific material was not called for in the contract, the contractor elected to use common construction-grade Styrofoam polystyrene packing. Two 1-7/8-in-thick layers were placed over the lightweight concrete and extended over the original shaft collar.

The purpose of using compressible packing was to allow for possible differential movement among the reinforced concrete top slab, the foundation footings, the central core plug of lightweight concrete, or the original shaft collar. The possibility of differential ground movements between any of the structural elements must be considered.

Later tests of similar Styrofoam polystyrene material at the Spokane Research Center indicated the material has an extremely low elastic modulus and little strength. It was concluded that the Styrofoam polystyrene compressible packing used at the No. 22 shaft should sustain more than 2 in of compression without difficulty.

REINFORCED CONCRETE SURFACE SEAL

The final surface seal was a 21- by 17-ft reinforced concrete slab that extended onto the footings placed outside the perimeter of the original shaft. The depth of the slab exceeded 16 in to allow for an increase in slab thickness for the 5-psi surcharge loading and an adequate concrete cover for the steel beams and rebar. A slope of 1/4 in/ft from the centerline was specified for water drainage, resulting in a thickness of 16 in along the outer edges and 18-1/4 in at the centerline. Including the additional thickness between the steel beams and the Styrofoam polystyrene packing, the monolithic thickness of the concrete at the central core directly above the original shaft was 22 in.

A bottom primary mat of No. 8 rebar was laid on 12-in centers parallel to the steel beams. Secondary No. 5 rebar was laid on 15-in centers. The top mat was No. 4 rebar on 12-in centers with secondary No. 4 rebar on 12-in centers. Because of the number of connections in these two rebar mats (nearly 400 for each), all of which had to be hand tied, this task took more time than expected (fig. 22).

Approximately 22 yd^3 of concrete was placed within 3 h (fig. 23). Mix was hand shoveled along the centerline to build the slope, and the entire surface was then leveled with a screed (fig. 24).

Concrete mix design provided by the ready-mix supplier was a basic 6-sack mix with 1 sack of fly ash substitution (by volume) as follows:

Ingredient	*Amount*
Cement (5 sacks, Type II)	470 lb
Fly ash	70 lb
Water, 27.6 gal	230 lb
Sand	1,324 lb
No. 57 limestone	1,780 lb
Total	3,874 lb
Water-reducing admixture	5 oz/cwt
Air-entraining agent	1.10 oz/cwt
Design unit weight	143.48 lb/ft^3
Slump	3 in
Air content	7.5%
Water:cement ratio	0.426

This mix design was approved by WVDEP. Tests of this mix at an independent testing laboratory gave results of 4,400 psi at 28 days. No test cylinders were taken by the USBM during this project. This same mix design was used for all normal-weight concrete at the No. 22 shaft closure.

VENT TUBE PLACEMENT

The purpose of the vent tube through the central concrete core was to vent methane and to serve as an access way for future observations, if needed. The vent tube was placed in the corner of the shaft farthest from the county road to prevent possible vehicle disturbance and to serve as a permanent marker. The design called for the vent tube to be in telescoping sections. A sheathing tube completely penetrated both the lightweight concrete core and the normal-weight concrete cap. The lower sheathing tube, which extended from approximately 1 ft below the platform assembly within the shaft upward through the core to just below the steel beams, was 8 in. in diameter and 11 ft long. The second tube was designed to allow for possible movement or settling between either the top slab or the lightweight concrete core. This tube was a 15-ft section of 6-in pipe placed within the 8-in sheathing tube. Approximately 3 ft extended above the ground surface. The connection was hand-packed with concrete just above the lightweight concrete (fig. 25). All vent tube piping was polyvinyl chloride (PVC), schedule 40, ASTM D-1785. To

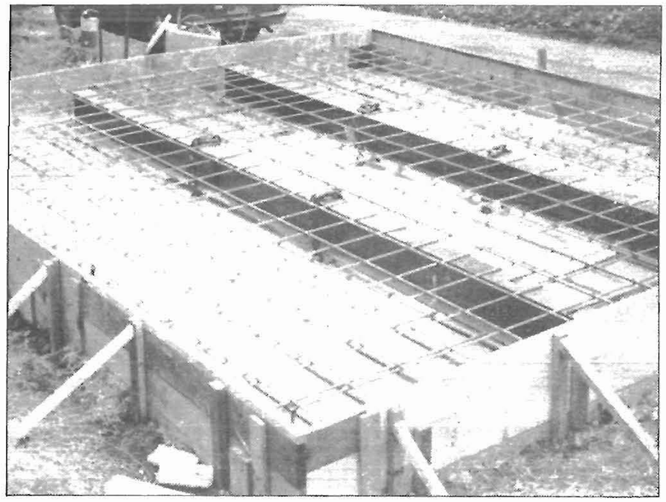

Figure 22.—Rebar cages just before final concreting of cap. Note compressible packing just below beams.

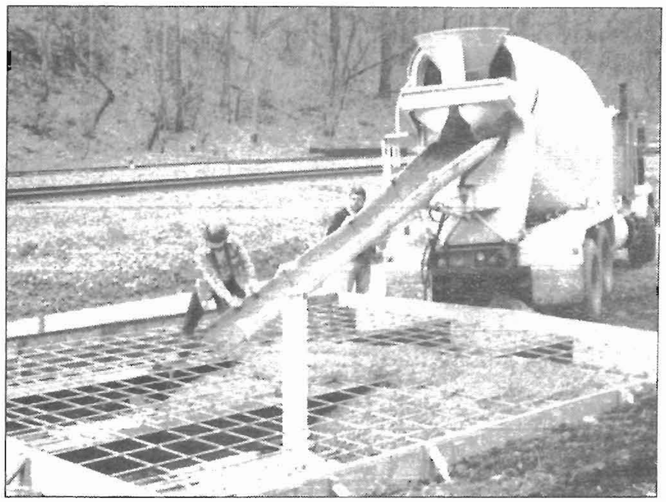

Figure 23.—Concreting reinforced surface cap.

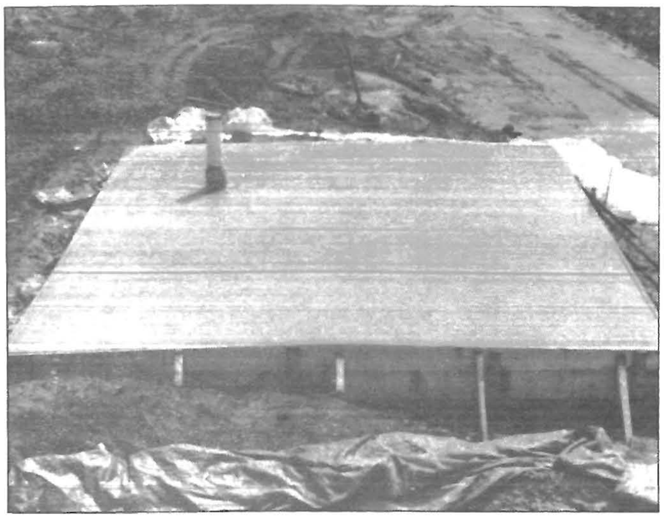

Figure 24.—Completed shaft capping of reinforced concrete.

Figure 26.—Hand-packing grout between protective steel casing and vent tube.

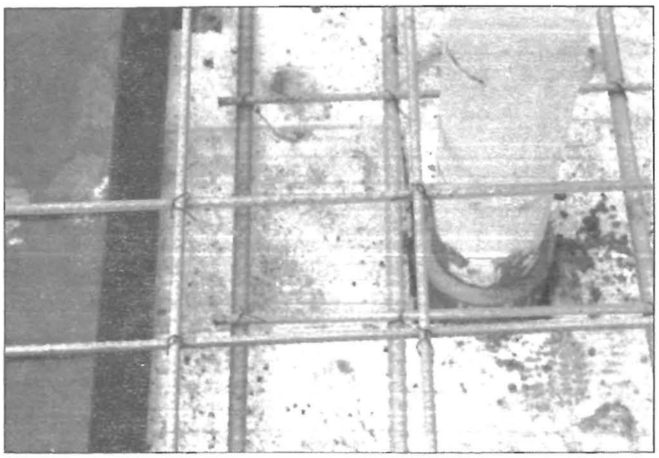

Figure 25.—Detail of vent tube placement. Upper tube is shown inside sheathing tube, which extends completely through lightweight concrete core.

provide surface protection and prevent vandalism, an 18-in length of 8-in-diam steel pipe[11] was placed around the protruding PVC pipe and embedded about 1 ft deep in the fresh concrete of the top surface slab. The joint was hand-packed with concrete (fig. 26). An additional PVC section with an elbow joint and flame arrestor was later installed on top of the 6-in pipe.

LANDSCAPING AND RESEEDING

An equally important part of the project was landscaping and reseeding the site (*16*, pp. 19-24). This work was directed by WVDEP because its earlier reclamation projects had been successful. The contractor was required to clear the site of all remaining construction debris and unsalvaged materials, large rocks, and refuse. The topsoil was reworked and contoured within the existing topography at the site, and the shaft was covered with approximately 12 in of reworked topsoil. Specifications called for reseeding immediately following completion of the final grading before rainfall could erode the site. Commercial 10-20-10 fertilizer at the rate of 1,000 lb/acre and agricultural-grade limestone at a rate of 3 ton/acre were spread for seedbed preparation.

Seeding schedules depended on the season. Spring seeding required a mixture of 15 lb/acre of annual ryegrass, 40 lb/acre of tall fescue (KY-31), 15 lb/acre of birdsfoot trefoil, and 20 lb/acre of crown vetch. All seed was certified and properly inoculated for growth. Mulching was done immediately following seeding. The WVDEP contract made the contractor responsible for the site for 1 yr following project completion, during which time reseeding or further reclaiming might be necessary if erosion occurred. The vegetation growth approximately 8 weeks following project completion is shown in figure 27.

Erosion and sediment control were also part of project specifications (*16*, pp. 17-18). Silt-control fencing and straw bales staked into the ground were specified for temporary sediment control. The location of such fencing and bales was at the direction of the engineer. After the second year of seeding, these erosion and sediment controls were to be removed. Because of low water flows along Pine Creek during this project, minimal erosion control was needed.

[11] Future designs might involve the use of telescoping sheathing pipes of steel that would completely penetrate the lightweight concrete and the normal-weight concrete top slab with the PVC vent tube extending through both pipes. Another design modification would be to place the sheathing tube several inches away from the shaft wall to ensure concrete flow behind the vent pipe.

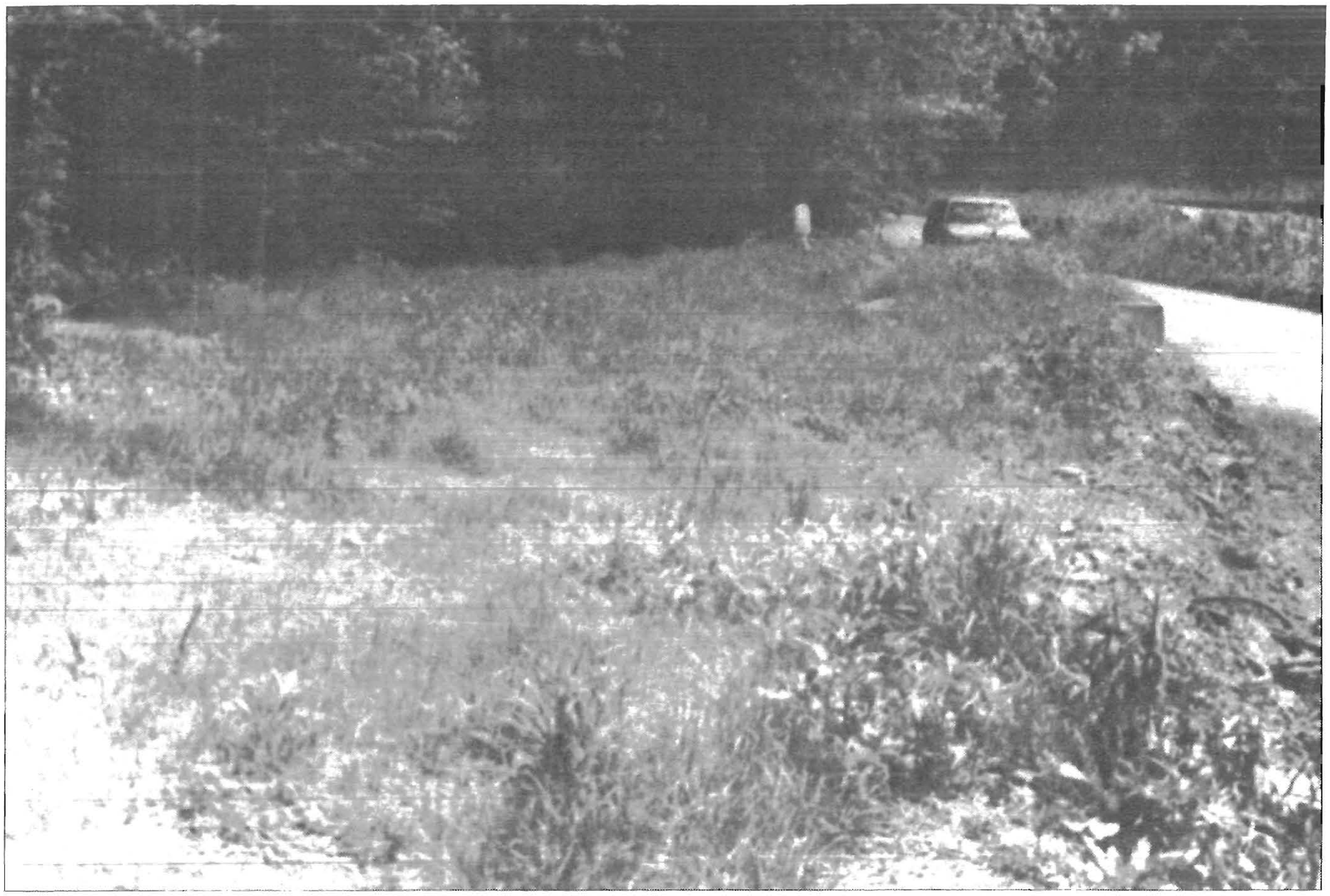

Figure 27.—Vegetation growth on shaft site after landscaping and grass seeding.

INSTRUMENT EVALUATION

Initially, in the generic design phase, an instrumentation program was considered to evaluate the long-term stability and subsidence of the mine seal. Methane gas, moisture conditions, and spontaneous coal fires in the abandoned mine would also be monitored. Instruments such as piezometers, extensometers, strain gauges on structural members, pressure and load cells, tilt level gauges, ultrasonic and other nondestructive gauges, nuclear moisture gauges, and thermocouples were all evaluated, as well as instruments used at other USBM projects. However, future subsidence could be measured from the concrete slab, and long-term methane levels, as well as spontaneous coal fires, could be monitored through the vent tube. These are all possible options for future AML projects where instrumentation is necessary. Because of budget constraints, instruments were not placed to monitor future shaft behavior.

GENERIC SHAFT DESIGN AND CONSTRUCTION TASK SUMMARY

Abandonment procedures for shafts and adits have previously utilized various simple methods of closure: backfilling with local fill materials of unknown properties, sealing with inadequate concrete capping, fencing, or boarding over with salvaged materials. After abandonment, sites are exposed to many environmental changes, such as ground water, seasonal weather, subsidence and other ground movements, and further chemical and physical deterioration over time. With passage of PL 95-87, the reclamation of abandoned mine lands has become a more engineered and research-oriented problem. The USBM's work described here was based on this research and engineering need.

Two points related to construction during this project are mentioned. None of the construction tasks were difficult, even for the small business reclamation contractor, although perhaps they were more time consuming because of a lack of proper equipment. The application of concrete sealants and waterproofing were easily scheduled into the construction sequence without delaying essential tasks. These measures were relatively inexpensive when using materials readily available from the coal mining industry. However, their long-term durability in an abandoned coal mine environment remains to be seen. Although the contractor had no experience with lightweight concrete, and initially expressed apprehension, the completion of the pour to specification was done without difficulty. Additives to normal-weight concrete were within present concrete technology and were used without difficulty.

Although conditions at abandoned mine sites will certainly vary from site to site, the procedures and methods described in this RI could be implemented at most AML sites under similar conditions.

CONCLUSIONS

A permanent mine seal for an abandoned coal mine shaft in Logan Co., WV, was designed by the USBM under a cooperative agreement with WVDEP (*31*). The shaft site lay alongside a flowing creek between a county road and an adjacent railroad spur line, which serviced nearby active surface coal mines. The design goal of the shaft seal was a service life of 100 yr and a surcharge load capacity of 5 psi. In view of the range of future scenarios for possible events over the next 100 yr, this loading design is conservative.

The featured material in the USBM's demonstration project was lightweight concrete in the wet density range of 45 lb/ft^3. This concrete attained a compressive strength of 200 psi at 7 days and over 300 psi at 180 days. Although lightweight concrete has been used in other construction and geotechnical projects, this is the first use of lightweight concrete at a USBM demonstration project in the AML program. The lightweight concrete shaft plug served to stabilize the original concrete shaft liner and the adjacent soil, thus preventing soil failure around the collar, which might otherwise undermine a concrete cap at the surface. The use of this material increased the practicability of this design, since the weight of lightweight concrete is only about 30% the weight of an equal volume of normal-weight concrete. Cost savings were realized in the design of a totally supporting structure because of the reduced weight of the suspended plug. With the lightweight concrete expected to bond to the shaft walls, the integrity of the entire shaft closure design was enhanced.

Other concrete technologies were also used to provide increased waterproofing and concrete durability. Exposed surfaces and shaft walls were waterproofed with a fiber-reinforced silicate coating. All exposed metal was painted with a rust-resistant paint, all rebar was coated with epoxy, the suspended shaft platform was wrapped with a geomembrane, and silica fume was added to the lightweight concrete mix to decrease permeability. Other additives commonly used in concrete construction were used in the concrete mix without difficulty. It is acknowledged that the waterproofing and sealing of concrete surfaces for long-term durability, such as 100 yr, is a difficult task, especially considering the acidic waters common on abandoned coal mine lands.

No construction problems were experienced, and the project was completed without incident, even though safety hazards, especially methane, at abandoned mine shafts require careful attention. The final contract cost for No. 22 shaft was $33,612 (1992), not including revegetation, engineering, and design costs.

Another USBM research objective was to develop a broad generic design concept for other shaft-sealing and adit-sealing problems, both within the AML program and throughout the mining industry. This objective will help stimulate the AML design community toward new and innovative techniques in mine sealing in the future.

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APPENDIX A.—EVALUATION OF LIGHTWEIGHT CONCRETE

Thirty-seven batches were mixed and placed: 12 in the first pour, 13 in the second, and 12 in the third. Each was batched at about 1 yd^3. Actual pumping times were less than 1 h for pour 1, 40 min for pour 2, and 40 min for pour 3. At no time was the contractor's equipment used to capacity. No difficulties were experienced with any pour. The time between pours 1 and 2 was 6-1/4 h, and between pours 2 and 3 approximately 14 h. The 1-h time interval specified for applying the waterproofing coating was easily met and did not interfere with essential work tasks. Twenty percent of the batches were monitored for wet unit weight in the field; this ranged from 40.6 to 48.0 lb/ft^3 and averaged 45.7 lb/ft^3. The target density of 45 (-5 or +4) lb/ft^3 was closely met. Achieving specifications was attributed to contractor experience.

Test cylinders were taken from the end of the 120-ft hose and poured into plastic sample molds after checking wet field weight. A sample group with wet field weights of 44.6 lb/ft^3 were taken to the USBM's Spokane Research Center for testing. Results of compressive strength tests of three samples in each test group are shown in table A-1.

Table A-1.—Results of compression tests at 7, 28, 90, and 180 days

Test series	Unit weight, lb/ft^3	Compressive strength, psi
7-day	43.55	200.0
	43.64	198.5
	42.76	197.5
28-day	42.96	229.6
	42.52	227.2
	42.74	221.2
90-day	41.43	306.7
	41.17	263.7
	41.85	341.65
180-day	38.62	327.8
	38.12	350.5
	36.59	445.0

All test cylinders were 3 in. in diameter and 6 in long and remained in the sampling molds until the day they were tested. The exceptions were those samples used in the 180-day tests, which were samples that had been saved from each of the prior test groups and air dried in the office. The 180-day samples had the highest compressive strengths, with a general strength increase from about 200 psi at 7 days to over 300 psi at 180 days (table A-1). For the 28- and 90-day tests, the average elastic modulus was approximately 1.75×10^4 psi, while the air-dried 180-day samples had an elastic modulus of approximately 1.0 to 1.5×10^5 psi, an increase of a factor of 10. The elastic modulus was determined from the initial straight line portion of the stress-strain curve. Only samples tested at 180 days emitted sounds during the breakage.

Additional laboratory tests included oven drying and water soaking. One group of samples was oven dried for 3 days at 200° F, after which the samples showed a decrease of approximately 22% in weight. These samples were then left on an office shelf and allowed to reabsorb moisture (approximately 14% after 250 days). Water immersion tests on another group of samples showed water absorption of about 15% (based on stripped form weights) after 250 days. Both sample sets had a near-constant weight change after approximately 180 days, with the weight changes gradually decreasing toward the end of the test period.

To further understand the structure of lightweight concrete and to ascertain its long-term durability, scanning electron microscopy (SEM) studies were done at the USBM's Albany Research Center, Albany, OR. To make SEM photos (fig. A-1), samples from the 7-day, 28-day, 90-day, and 180-day test series were sectioned, coated with 60/40 AuPd alloy, and 20 kV, 10-power secondary electron images photographed. Generally, a uniform spherical bubble size was apparent. This structure was distributed uniformly throughout the cement matrix. Few differences were observed among the samples. Effects of adding microsilica were not apparent. Differences noted subjectively were the amount of detrital material within the bubble shell, perhaps resulting from the method of cutting a section, and the increase in hardness with age. In the older samples, the bubble walls appeared to have a more distinctive sheen, perhaps also reflecting hardening of the bubble rim.

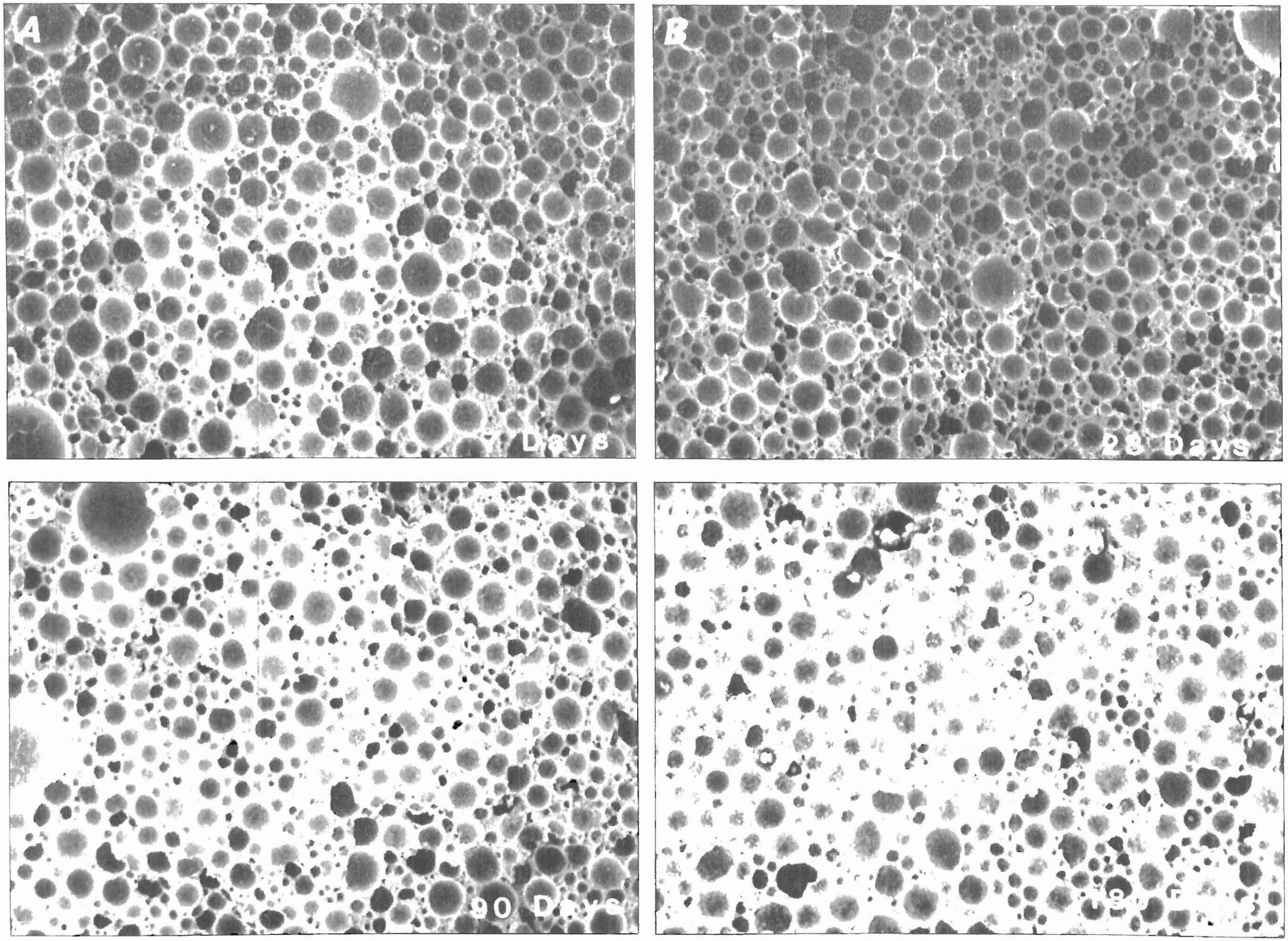

Figure A-1.—Scanning electron microscope image of surface (X 10). *A*, 7 days; *B*, 28 days; *C*, 90 days; *D*, 180 days.

APPENDIX B.—LUMP SUM BID ITEMS

The following lump sum bid items for the No. 22 shaft were included in the contract bidding documents by the State of West Virginia (*16*, p. 25).[1]

1.0 Mobilization
2.0 Construction surveying
3.0 Quality control
4.0 Clearing and grubbing
5.0 Utilities
6.0 Pine Creek shaft, No. 22
7.1 Footings preparation
7.2 Shaft interior preparation and platform installation
7.3 Preparation for and installation of lightweight concrete
7.4 Preparation and installation of the top slab overlay
8.0 Erosion and sediment control
9.0 Revegetation

All contract offerings were entered into between the State of West Virginia Division of Environmental Protection and the contractor by sealed competitive bid submitted to the state purchasing director, Capitol Building, Charleston, WV. Subsequent selection of the contractor and contract requirements were under the direction of the State of West Virginia contracting code. The final contract cost for No. 22 shaft, excluding revegetation and engineering design, was $33,612 (1992 dollars).

[1]Italic numbers in parentheses refer to items in the list of references preceding the appendix.

APPENDIX C.—LIST OF MATERIALS

Because of variations in material and labor costs depending on the individual shaft site, as well as varying dimensions at each site, a detailed cost analysis is not included. Rather a list of materials is provided to assist in future cost estimates and contracts. The list is based on both design and field-adjusted quantities for the No. 22 shaft.

Concrete materials:

Footings, 4,000 psi (see report for mix)	8 yd^3
Cap seal, 4,000 psi (see report for mix)	22 yd^3
Lightweight concrete, 45, -5 +4 lb/ft^3, 100 psi minimum	37 yd^3

Ventilation tubing:

Vent tube, 6 in diam, 15 ft long, Sch. 40, PVC, ASTM D-1785	1 pc
Lower sheathing tube (for vent tube), 8 in diam, 11 ft long, Sch. 40, PVC, ASTM D-1785	1 pc
Protective sheath, 8 in diam, 5/16-in-thick wall, 18 in long, A 36 steel	1 pc
Elbow joint with connections, 6 in diam, various lengths to fit, Sch. 40, PVC, ASTM D-1785	3 pc
Flame arrestor cap assembly	1 ea

Downshaft steel platform:

Steel beam, A 36, 4 WF 13	43 ft
Steel plate, A 36, 5/16 in thick	75.6 ft^2
Steel angles, A 36, L 4 by 4 by 1/2 in	38 ft
Lower hanger angles, A 36, L 6 by 4 by 1/2 in, with holes	4 ft
Steel beams, A 36, 12 WF 30, 20 ft long	2 ea
Clevises, No. 3, with 7 UNC-2B thread, 1-1/4 in diam (for four at top, use extra-wide grip)	8 ea
Tie-rods, 1-1/4 in diam, threaded both ends, 8 ft, 9 in long, A 588 grade 50	4 ea
Tie-rod jam nuts, 1-1/4 in ID, with 7 UNC-2B thread	8 ea
Bolts and nuts (for clevis), 1 in diam, with nuts, grade A 588	8 ea
Chain, 3/4-in link, NACM grade 43, cut to four equal lengths, each 66 in long	22 ft
Connecting links, with pin and cotter	4 ea
End links	4 ea
Corrosion-resistant paint, commercial grade	3 gal

Geomembrane liner, Hypalon:

Upper sheet, 8 ft, 11 in by 8 ft, 6 in	1 ea
Bottom sheet, 11 ft, 6 in by 12 ft	1 ea
Gluing strips, 2 by 40 ft, cut in field as needed	
Glue, manufacturer-recommended Hypalon glue	3 qt
Duct tape (protective taping along edge of geomembrane liner to prevent tearing along shaft wall)	
Compressible packing, 4- to 6-in-thick Styrofoam or similar compressible material	192 ft^2
Waterproof coating, fiber-reinforced, silicate base, hand-troweled, applied in two-pass coat	800 ft^2

Rebar for lightweight concrete:[1]

Support for foam concrete, No. 6, 8 ft, 6 in long, sets of two, one set for lower rebar, one for upper	34 ft
Lower rebar support plates, 4 by 4 by 1/4 in with hole (placed over tie-rods)	4 ea

Lightweight concrete mats:

No. 4, 8 ft, 6 in long	119 ft (14 pcs)
No. 4, 9 ft long	126 ft (14 pcs)

Rebar for footings:

Footings, primary, No. 6, 16 ft long	320 ft (20 pcs)
Footings, secondary, No. 6, 3 ft, 6 in long	168 ft (48 pcs)
Footings, primary, No. 6, 20 ft, 6 in long	246 ft (12 pcs)
Footings, secondary, No. 6, 1 ft long	48 ft (48 pcs)

Cap seal concrete reinforcement:

Lower mat, primary, No. 8, 20 ft long	340 ft (17 pcs)
Lower mat, secondary, No. 5, 4 ft, 6 in long	67.5 ft (15 pcs)
Lower mat, secondary, No. 5, 5 ft, 6 in long	165 ft (30 pcs)
Upper mat, primary, No. 4, 20 ft long	340 ft (17 pcs)
Upper mat, secondary, No. 4, 16 ft long	336 ft (21 pcs)

[1]All rebar was grade 60, thermax treated, and expoxy coated.

Bracing rebar to prevent overturning of beams (optional):

No. 4, 5 ft long (weld across ends of 12 WF 30)	20 ft

Revegetation:

Regrading and seedbed preparation	±1 acre
Fertilizer (10-20-10)	1,000 lb/acre
Agricultural-grade limestone	3 ton/acre
Annual ryegrass	15 lb/acre
Tall fescue (KY-31)	40 lb/acre
Birdsfoot trefoil	15 lb/acre
Crown vetch	20 lb/acre

Erosion and sediment control:

Straw bales	As required
Sediment control fencing	As required
Staking materials	As required

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